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ABSTRACT

This document contains the four keynote papers from ICCE/ICCAI 2000 (International Conference on Computers in Education/International Conference on Computer-Assisted Instruction). "Using Technologies To Model Student Problem Spaces" (David Jonassen) contrasts examples of semantic network, expert system, and systems modeling representations of problems and presents a research agenda for examining the efficacy of these tools. "Millennium eLearning: The Next Killer Application: Implications for Educators and Information Professionals" (Ching-Chih Chen) describes the millennium eLearning development, particularly in the United States, and discusses related problems and issues. "Social and Technological Innovations for a Knowledge Society" (Marlene Scardamalia) discusses core facets of knowledge creation, knowledge building technology, and knowledge building social structures. "Computer-Based Strategies for Articulate Reflection (and Reflective Articulation)" (John Self, Erol Karakirik, Ah-Lian Kor, Patricia Tedesco, and Vania Dimitrova) discusses reasons for the increased emphasis on learning systems providing an environment not just for practice, but also for articulation and reflection. Strategies for promoting articulate reflection are illustrated with reference to five systems. (MES)

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Proceedings

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Using Technologies to Model Student Problem Spaces

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Problem solving is generally regarded as the most important cognitive activity in everyday and professional contexts. Research on the application of multiple representations in learning makes it clear that the key to problem solving is rich, integrated, multiple representations of the problem space. Computer-based cognitive tools can be used as formalisms to help learners to represent the problem space of problems they are learning to solve. In this presentation, examples of semantic network, expert system, and systems modeling representations of problems will be contrasted. A research agenda for examining the efficacy of these tools will be presented along with some preliminary prescriptions for problem-specific problem representation tools.

Keywords: **problem solving, multiple representations, problem space, cognitive tools**

1 Introduction

I assume that the primary intellectual purpose of all education should be to teach students to solve problems. If educational institutions agreed, they would have to increase their emphases on learning to solve problems. Why should they? 1) Problem solving is at the heart of practice in professional and everyday settings. Professionals are paid to solve problems, not to complete exams, write prescriptive papers, or complete canned laboratory exercises. 2) Requiring learners to only memorize information for tests is not important, relevant, or transferable to everyday and professional practice. 3) Additionally, memorization for examinations models immature, absolutist epistemic beliefs (beliefs about what knowledge is and how we come to know it), thereby restraining learners' intellectual development. Modeling and reinforcing memorization is intellectually stultifying and restricts mental and brain development [1]. Finally, most contemporary learning environments (constructivist learning environments, problem-based learning, goal-based scenarios, anchored instruction, etc.) and learning theories (situated learning, social cognition, everyday cognition, case-based reasoning, etc.) support different forms of problem solving, even though they have not articulated the nature of the problem-solving processes being supported. Problem solving is at the heart of contemporary research and theory. Although problem solving is tacitly accepted as an essential life skill, too few instructional efforts support learning how to solve problems.

An exception to the absence of problem solving in curricula occurs regularly in science and math courses at public schools and universities. Instructors pose problems in these disciplines all of the time. However, there are at least two limitations of these problem-solving activities. 1) The problems that are solved are almost exclusively well-structured problems that have convergent solutions and known, teachable solution paths. 2) These problems are too often taught as procedures, so they are learned as procedural processes bereft of the conceptual understanding necessary to transfer those procedures to new problems or to similar problems in different contexts or reason beyond the procedures. As a result, students rely on formulaic approaches that do not support transfer of existing skills, let alone the ability to solve complex and ill-structured problems that are regularly faced by practitioners. When students are learning to solve problems, there are a number of reasons for poor problem-solving performance among students:

1) When solving problems, students are typically taught to represent problems in a single way (too often memorization). Representing what learners know in only a single way engages only a single set of cognitive representation skills that use only a single formalism for representing their knowledge. Therefore, students' understanding of what they are studying is necessarily constrained. Understanding for problem solving requires multiple integrated representations of what we know. Mayer and Greeno [2] found that students who were taught to solve probability problems by calculating a formula versus learning about the conceptual meaning of the variables represented and solved the problems very differently. The way that a problem is represented determines how the problem is solved. Students in a physics class at Harvard who were competently solving physics problems that were represented mathematically failed a test of conceptual understanding of the problems and their underlying principles [3]. Students could apply equation-based problem-solving procedures without understanding the physics concepts they were representing mathematically, so they were unable to transfer their skills because of their limited conceptual understanding. The over-emphasis on teaching procedural, quantitative models necessarily limits students' understanding of the problem. They represent the problem mentally as a series of solution steps. More emphasis on learning to qualitatively represent problems is needed. Ploetzner, Fehse, Kneser, and Spada [4] showed that when solving physics problems, qualitative problem representations are necessary prerequisites to learning quantitative representations. When students try to understand a problem in only one way, they do not understand the underlying systems they are working in. Multiple models are needed to represent performance at the skill-, rule-, and knowledge-based levels[5]. In order to solve problems, Rasmussen argues that we need to understand the system in which the problem is embedded at different levels of abstraction, including the physical form, physical functions, generalized functions, abstract functions, and functional purpose. Although these abstraction types are likely to vary with the nature of the problem, the conclusion is clear. Successful problem solving requires different kinds of knowledge represented in different ways. I believe that at least three knowledge types are important: conceptual or systemic knowledge, procedural knowledge, and strategic knowledge. Extensive research is needed to identify the knowledge bases required for different kinds of problem solving.

2) The most commonly encountered problems, especially in schools and universities, are well-structured problems. Typically found at the end of textbook chapters, these well-structured problems require the application of a finite number of concepts, rules, and principles being studied to a constrained problem situation [6]. Ill-structured problems are the kinds of problems that are encountered in everyday practice, so they are typically emergent dilemmas. Because they are not constrained by the content domains being studied in classrooms, their solutions are not predictable or convergent. They may also require the integration of several content domains.

Jonassen [7] has articulated a typology of problems, including logical problems, algorithmic problems, story problems, rule-using problems, decision making, troubleshooting, diagnosis-solution problems, strategic performance, case analysis problems, design problems, and dilemmas. Within each category, problems vary with regard to abstractness and complexity. The specific learning outcome for each of these problem types as well as the criteria for judging the success of problem solutions varies. Well-structured problems focus on correct, efficient solutions, while the ill-structured problems focus more on decision articulation and argumentation. There are many types of problems, most of which are not well understood. However, it is reasonable to assume that different problems engage and require different intellectual skills, which makes it even less likely that any single form of problem representations will work with al problems.

2 Constructing the Problem Space

I believe that the most important cognitive activity in problem solving is constructing the problem space, that is, representing the problem. Why? 1) Research confirms that the quality and modality of problem spaces best distinguishes experts from novices [8]. Novices focus too much on surface features of the problem in their representations, while experts represent problems in terms of their principles and abstractions of processes. This enables them to recognize problem types more efficiently than novices. 2) Different problems require different kinds of problem spaces (emphasizing different components or modalities [7]. 3) Multiple representations scaffold understanding and solution development, but they place a burden on working memory. Based on cognitive load theory, integrating multiple representations places high demands on working memory [9]. While representing problems in multiple ways provides richer representations in memory, learners need to learn how to integrate these representations.

The conclusion from this research is clear: if we want students to become better problem solvers, we must explicitly teach or scaffold problem space construction.

2.1 Using Technologies for Modeling Problem Spaces

Modern technologies afford learners numerous methods for representing what learners know. When learners use technologies to represent what they know, the technologies function as cognitive tools or Mindtools [10]. Cognitive tools are any technologies that amplify the learners' thinking by enabling learners to represent what they know using different representational formalisms. As knowledge representation formalisms, cognitive tools are premised on the idea that humans learn more from constructing and justifying their own models of systems than from studying someone else's. Using cognitive tools to represent their own understanding necessarily engages learners in a variety of critical, creative, and complex thinking, such as evaluating, analyzing, connecting, elaborating, synthesizing, imagining, designing, problem solving, and decision making [7,10]. When using computers as cognitive tools, learners are teaching the computer, just as artificial intelligence researchers do when they build intelligent systems. However cognitive tools represent AI in reverse: rather than having the computer simulate human intelligence, we require the human to simulate the computer's unique intelligence and come to use it as part of their cognitive apparatus [11]. When learners internalize the tool, they begin to think in terms of it, thereby amplifying their cognitive skills.

In this presentation, I will demonstrate three technology-based knowledge representation tools (semantic networking, expert systems, and systems modeling) for modeling different kinds of problems that students are learning to solve. Semantic networking tools enable students to model conceptual knowledge. Expert systems enable students to model their procedural knowledge. Systems modeling tools enable students to model their dynamic and strategic knowledge. Externalizing learners' problem spaces using these technology tools will enable learners to articulate and collaborate on the construction of richer, multi-faceted problem spaces that are necessary for solving more complex and ill-structured problems.

2.1.1 Semantic Networks for Modeling Conceptual Knowledge

Semantic networks, also known as concept maps, are spatial representations of concepts and their interrelationships that are intended to represent the knowledge structures that humans store in their minds [12]. These knowledge structures are also known as cognitive structures, conceptual knowledge, structural knowledge, and systemic knowledge. Semantic networks are graphs consisting of nodes representing concepts and labeled lines representing relationships among them. Most semantic networking programs also provide the capability of adding text and graphical representations to each node.

Semantic networking is the process of constructing those maps — of identifying important concepts, arranging those concepts spatially, identifying relationships between those concepts, and labeling the nature of the semantic relationship between those concept. These maps are used by learners to represent what they are learning as multidimensional networks of concepts. Meaningful learning requires that learners connect new ideas to knowledge that they have already constructed. Semantic networks help in organizing learners' knowledge by integrating information into a progressively more complex conceptual framework. That is, they scaffold semantic organization processes in learners. When learners construct concept maps for representing their understanding in a domain, they reconceptualize the content domain by constantly using new propositions to elaborate and refine the concepts that they already know. More importantly, concept maps help in increasing the total quantity of formal content knowledge because it facilitates learners to use the skill of searching for patterns and relationship. That is important because well-organized and integrated domain knowledge is essential for problem solving.

Semantic networking tools assist learners in representing the underlying conceptual knowledge in a problem space. In order to use a semantic networking program to support problem solving, learners must identify the factors and variables, and concepts in a problem and use a semantic networking program to construct a conceptual representations of the problem. Examples of these will be demonstrated in the presentation.

2.1.2 Expert Systems for Representing Procedural Knowledge

Expert systems are artificial intelligence programs designed to simulate expert reasoning in order to facilitate decision making for all sorts of problems. Like a human expert, an expert system (computer program) is approached by an individual (novice) with a problem. The system queries the individual about the current status of the problem, searches its knowledge base (which contains previously stored expert

knowledge) for pertinent facts and rules, processes the information, arrives at a decision, and reports the solution to the user.

Building expert systems is a knowledge modeling process that enables experts and knowledge engineers to construct conceptual models [13]). This process focuses primarily on the explication of procedural knowledge that an expert (or at least a knowledgeable person) possesses. The expert system is the primary formalism for depicting procedural knowledge. But, expert systems do not necessarily have to be built be experts and knowledge engineers. In fact, using expert system shell programs, novices can easily learn to build expert systems to reflect their own procedural knowledge as it grows. Building expert systems requires learners to synthesize knowledge by making explicit their own reasoning, thereby improving retention, transfer, and problem-solving ability. Lippert [14] found that the analysis of subject matter that is required to develop expert systems is so deep and so incisive that learners develop a greater domain comprehension which is essential for problem solving. Building expert system rule bases engages learners in analytical reasoning, elaboration strategies such as synthesis, and metacognitive strategies. Having students construct small knowledge bases is a valuable method for supporting problem solving because of their emphasis on causal reasoning.

Expert systems assist learners in representing the underlying procedural knowledge in a problem space. In order to use an expert system program to support problem solving, learners must identify the decision factors and values of those factors that will predict a solution to the problem encode those values in a set of IF-THEN rules that represent the decision-making. Examples of these will be demonstrated in the presentation.

2.1.3 System Models for Representing Strategic Knowledge

Building models of real-world systems (representations that are abstracted from the details of a situation but grounded in the particulars of phenomena) is the basis of strategic scientific thinking. Building models and simulations requires diverse mental activities such as planning, data collecting, collaborating and accessing information, data visualizing, modeling, and reporting [15]. A systems model is a conceptual, conjectural representation of the dynamic relations among factors in a system, resulting in a simulation that imitates the conditions and actions of it. These dynamic simulation models represent the changing nature of system phenomena. Systems modeling tools use a simple set of building block icons (stocks, flows, converters, and connectors) to construct a map of any dynamic process. These tools enable learners to run and test the model that they have created and observe the output in graphs, tables, or animations. Constructing systems models supports the construction of strategic understanding of a problem system.

Systems modeling assists learners in representing the dynamic relationships among factors in any problem space. In order to use a systems modeling tools to support problem solving, learners must identify the all of the dynamic factors and values of those factors that will predict a solution to the problem and encode those values in stocks and flows that represent the way that the system works. Systems modeling is perhaps the most intellectually engaging activity that students can ever perform. Examples of these will be demonstrated in the presentation.

3 Research Questions

The effects of using cognitive technologies to support the problem representation process are not known. Extensive research is needed, and the topic justifies that effort. We must help to develop a new generation of problem solvers. That research will be guided by research questions such as these:

- Are there classes of problems that share similar problem representations structurally and conceptually?
- If so, will those classes of problems be represented equally well by the different tools?
- How domain-specific are those problems? That is, how similar or different are cognitive requirements among classes of problems in different domains (e.g. science, political science, economics, mathematics)?
- Can those cognitive requirements be scaffolded through the use of cognitive learning technologies? That is, can students improve their conceptual/procedural/strategic understanding of domain knowledge as well as problem solving abilities through modeling their understanding of problem within classes?
- Will learners be able to integrate these multiple representations into a coherent understanding of the problem?

- How can we design problem-specific environments that scaffold the development and integration of multiple problem representations in support of problem solving?

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Millennium eLearning: The Next Killer Application

Implications for Educators and Information Professionals

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The rapid technological change in the last decade and the fast proliferation in the use of the Internet and World Wide Web have indeed transformed the way we live, work, communicate and learn. With the shifting market and social conditions, our education systems are challenged with providing increased quality educational opportunities to more people who have not been reachable by traditional educational means. To answer this challenge, technology-based distance education has been introduced. On the other hands, with the introduction of the Next Generation Internet, together with powerful web-based systems and authoring tools, many, including commercial entities, have considered eLearning the next killer application. The playing field of higher education has become more and more crowded and muddy. While potentials for this development are obvious, so are many problems and issues. This speaker intends to describe the millennium eLearning development, particularly in the US, and discuss some of the complex problems and issues facing us. Implications for educators and information professionals will be explored in the hope to stimulate more creative use of technology among these professionals in meeting the needs of the learning societies in this new Millennium.

I am delighted to take part at this exciting conference as we gathered together from all over the world to share our views on the creativity, caring, and commitments of the learning societies in this new millennium. We face great challenges at a time with unparallel opportunities and potentials. Never before in our history, there is a more pervasive change-agent on our campuses than information technology, which has transformed the way we learn.

As was introduced earlier, since February 1997, I have been privileged to serve as a member of President Clinton' s Presidential Information Technology Advisory Committee (PITAC). I would like to share with you some of the Committee' s deliberations. In the PITAC Report to President Clinton in February 1999, entitled *Information Technology Research: Investing in Our Future*, the Committee identified 10 vital areas that information technology will transfer. These include:

- Transforming the way we communicate,
- Transforming we deal with information,
- Transforming the way we learn,
- Transforming the practice of health care,
- Transforming the nature of commerce,
- Transforming the nature of work,
- Transforming how we design and build things,
- Transforming how we conduct research,
- Transforming our understanding of the environment, and
- Transforming government.

As to the transformation of the way we learn, a vision of learning transformed by information technology was articulated:

> *"Any individual can participate in on-line education programs regardless of geographic location, age, physical limitation, or personal schedule. Everyone can access repositories of educational materials,*

easily recalling past lessons, updating skills, or selecting from among different teaching methods in order to discover the most effective ways of learning. Educational programs can be customized to each individual's needs, so that the information revolution reaches everyone and personal digital libraries provide a mechanism for managing ones accumulated knowledge resources. Learning involves all our senses, to help focus each student's attention and better communicate educational material." (p.13)

This vision will drive progress in the 21st century. Yet, to realize this vision, there are many technical challenges and benefit. As stated in the same report:

"In addition to research to meet the scalability and reliability requirements for information infrastructure, improvements are needed in the software technologies to enable development of educational materials quickly and easily and to support their modification and maintenance. We know too little about the best ways to use computing and communications technology for effective teaching and learning, in particular, how to effectively use multimedia capabilities to create a richer, and more appealing learning experience. We need to better understand what aspects of learning can be effectively facilitated by technology and which aspects require traditional classroom interactions with the accompanying social and interactive contexts. We also need to determine the best ways to teach our citizens the powers and limitations of the new technologies and how to use these technologies effectively in their personal and professional lives." (p. 14)

The Report calls for the strengthening of use of information technology in education. Realizing that there are challenges and issues, a PITAC/Learning Panel was created to address these challenges, and draft more substantive recommendations, which are forthcoming at the later part of this year. However, some of the findings that will be used to support the Panel's recommendations were reported at the PITAC Public Meeting of September 20, 2000. They include:

- Information Technology, used within classroom settings with well-educated and motivated teachers, has the potential for providing many of the benefits of one-on-one tutoring.
- Information Technology that has been successfully applied in industrial and military training contexts has been effective and reduced costs.
- Current Web-based technologies are beginning to be applied in a grass-roots way in many educational and training contexts, but teacher training, absence of adequate educational performance metrics, the expense of developing materials, and lack of standard, application-level infrastructures are key barriers to more rapid diffusion of existing beneficial technologies and materials.
- The role of the teacher is changing and will continue to change.
- The most exciting and potentially beneficial E&T applications of IT require research that has yet to be done.
- The breadth and scale of the required research effort and the necessity for technology diffusion imply that partnerships of governments, industry, universities, and schools are essential.
- As a basis for future progress, current levels of computer access are inadequate. Computers and high-speed Internet connections are needed in every classroom, preferably for every student, and accessible from outside the school, preferably from every home or at least in readily accessible community centers that can provide access and appropriate training.

I am delighted to see that some of the similar issues and challenges are being addressed at this very meeting as well. While discussions and debates are ongoing everywhere on these learning related issues and challenges in the world, we are witnessing an explosive phenomenon with eLearning activities surging ahead in a speed unmatched in any other activities before. This development should have great implications for educators and deserve our close attention. This is why I have taken this opportunity to discuss the millennium eLearning, the next killer application.

1 INFORMATION TECHNOLOGY, INTERNET, NEW ECONOMY, AND EDUCATION

"The next big killer application for the Internet is going to be education."

John Chambers, CEO, Cisco Systems

While we, educators, are addressing the challenges facing us in this new information technology era, one thing is certain – with the dramatic technological development, and the wide spread use of Internet and World Wide Web in the most recent years, the new economy has moved at apace never seen before. According to Michael T. Moe, Director of the Global Growth Stock Research of Merrill Lynch, "the new economy is a knowledge economy based on brainpower, ideas and entrepreneurism. **Technology is the driver of the new economy, and human capital is its fuel.** The knowledge economy is people-centric. Or economy has evolved from manufacturing-intensive to labor-extensive. Fundamental to success in the new economy is how companies obtain, train and retain knowledge workers. The knowledge enterprise industry is over $2.2 trillion. We expect the online component to grow from $9.4 billion to 53.3 billion by 2003, a 54% CAGR" (Moe and Blodget, 2000). The evolutionary phases of e-Business shown in Figure 1 shows the predicted dramatic growth of e-Knowledge industry.

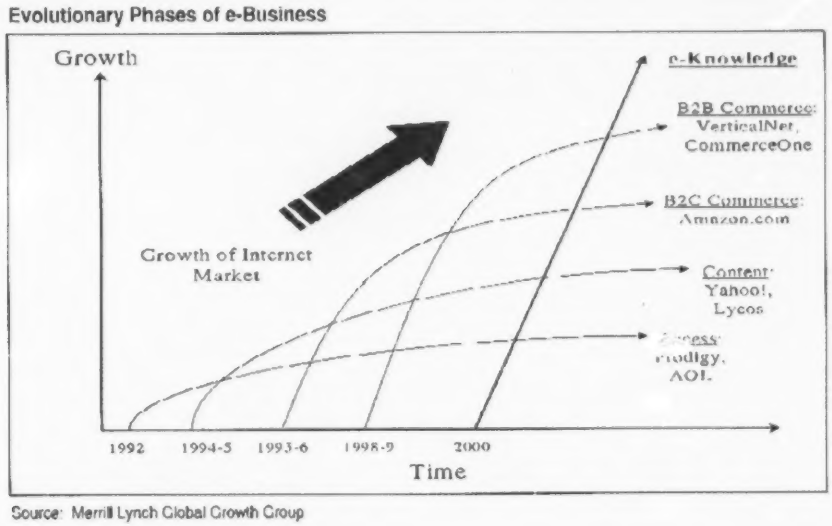

Figure 1. Evolutionary Phases of e-Business showing the sharp growth of e-Knowledge

In concert with the vision articulated in the PITAC report, Moe and Blodget state, "ubiquitous PCs and high-speed bandwidth will facilitate access to knowledge anytime, anywhere. The Internet democratizes knowledge, increasing access to it, lowering its cost and ultimately improving its quality. We believe combining the "richness" of an offline experience and "reach" that only the Internet provides creates a network effect that allows scale knowledge enterprises to be born. Moreover, we see significant potential advantages that offline operators can achieve by leveraging their experience and brand online."

Some Useful Statistics and Statements

From its modest beginning in the '60s and '70s, the Internet has quickly become the largest global communications network. The number of web sites via the Internet has increased from a mere 130 in 1993 to well over 17 million in 2000, according to the latest figure cited in the September 25, 2000 issue of *Infoworld* (Coopee, 2000). The Internet traffic is expected to top 15 million terabytes per month by 2003. This explosive growth can be translated from business point of view to huge potential for profits. Therefore, it is no surprise that to see the potentials for learning as described by Moe and Blodget in the following:

- Domestic online corporate learning is expect to grow from $1.1 billion in 1999 to $11.4 billion in 2003 (a 79% CAGR);
- At the end of 1999, more than 196 million people were using the Internet worldwide. The number of global Internet users is expected to more than triple to 638 million by 2004, a 27% CAGR;

- The e-knowledge market will reach $53.3 billion by 2003 from $9.4 billion in 1999, growing at a CAGR of 54%;
- These technology-intensive industries are growing 3-6 times as fast as economy-wide job growth;
- Colleges and universities are the most wired community on the Web, with over 90% of college students accessing the Internet, 52% of them daily. Students spend nearly 19 hours per week on the Internet, 84% of the time pursuing academic activities. College students currently spend $105 billion annually, with $1.5 billion of that online;
- Currently there are 84 million students enrolled in higher education worldwide. Global demand for higher education is forecasted to reach 160 million by 2025 – if online learning captures even half of this growth, there would be 40 million students for online education...The online higher education market will grow to $7 billion by 2003 in the US alone.
- The number of K-12 schools connected to the Internet has climbed from 35% in 1994 to 96% today... Today is the Generation "i" with 53 million schoolchildren, three million teachers and 23 million families, the K-12 marketplace encompasses a huge number of potential users. The Internet is the world's greatest library..that gives the same access to knowledge everywhere...

2 THE HIGHER EDUCATION

In discussing the impact of information technology on education, we should really cover all levels of education from K-12 to the highest level of research in our academic institutions. Yet, time does not permit me to do so here. I shall concentrate some of the following discussions on the higher education.

Again, Figure 2, taken from Moe and Blodget, provides an excellent overview of the enormous higher education market both in the US and the world, with 15-million students and 1-million faculty in the US, and 84-million students and 2.8-million faculty abroad, not mentioning the large number of alumni and other population who will need continuing education activities.

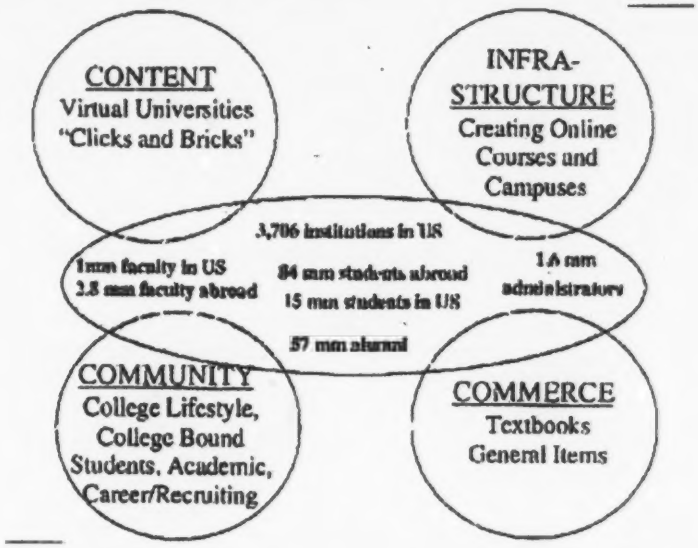

Figure 2. The higher education market (Source: Merrill Lynch Global Growth Group)

This speaks for the potentials for eLearning from each of the four components – Infrastructure, Content, Community, and Commerce.

Infrastructure

With the ever-increasing speed and high-bandwidth global network, and the coming of the Next Generation

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Internet, it is fair to say that the truly revolutionary impact of the Internet is just beginning to be felt. As technology reshapes the world, more than ever; institutions of higher learning has begun to take advantage of the technological advances that can provide more efficient ways of teaching and learning for their students, and can offer them exciting new opportunities as well.

Wireless Technology

In addition, wireless technology will begin to be utilized in big ways. Wireless business has grown so fast, and it is expected that it will grow from 1.2 billion in 2000 to about 4.6 billion in 2004. Currently, students at the School of Public Health of the Johns Hopkins University, for example, can literally access anything from their laptop via wireless network. In Pennsylvania, Widener University with the help of 3Com is making its library resources available to students totally via wireless network. Many other universities, like Cornell University and Carnegie Mellon University are also heading toward this direction. Commercially, online learning activities also test wireless waters in big ways, as reported in Informationweek.com*(July 24, 2000). For example, MindSurf, invested by $60 millions from Sylvan and Aether, will deliver pilot programs to schools nationwide beginning this school year. The goal of these programs is to encourage students and faculty to collaborate in real time using wireless devices, even when learning takes place outside the classroom, such as in a museum.*

Distance Learning and Virtual Universities

The technology and infrastructure are also in place to provide multimedia-intensive contents to people in rural, and isolated areas. For example, overcoming distance in rural education in East Texas that is full of isolated towns hundreds of miles apart, fibre-optics system is installed to provide distance-learning capabilities for students, teachers, and community members there. Thus, in the new economy, "distance" has been eliminated. In addition to "distance", learning opportunities are also wide open now for those working people who cannot afford to have the conventional higher education, or those who are homebound. So, the Internet has truly "democratize" education, increasing universal access to learning on-demand opportunities, and reducing its cost. As a result, "distance learning" becomes hot buzzword, and also great moneymaking enterprise.

"According to the US National Center for Educational Statistics, the number of institutions offering distance learning course has risen rapidly, from 33% of all colleges in 1995 to 58% of two-year and 62% of four-year public colleges today, with another 28% of two-year and 23% of four-year public colleges planning to start offering courses within the next three years. When translating these percentages to real students, according to estimates from International Data Corporation, 710,000 college students were enrolled in distance learning courses in 1998; the number is expected to soar to 2.2 million by 2002" (Computer-based learning, January 7, 2000). Thus, there is an explosive increase of distance learning courses offered via the Internet by all types of academic institutions. In addition, there is a proliferation of a different breed of universities, such as the Western Governors University (WGU), which claims to be "the university that comes to you" (www.wgu.edu). WGU is a degree-granting, competency-based, online, distance-education institution. 19 states and governors as well as 20 leading corporations and foundations support WGU. Its online catalog has nearly 1,000 distance delivered courses from 50 different education providers including colleges and universities, corporate providers, and independent learning resources. It established agreements with Bellevue University, Empire State College, Jones International University, Masters Institute, and Thomas Edison State College. Every W GU student is assigned a mentor – a WGU faculty member who is an expert in the student's field of study. The mentor provides one-on-one advising to help student determine what they need to learn, and where to go to get it.

From another angle, online leaming has found an enormously promising corporate market. We have seen that big monies are investing in this activity. It ranges from much smaller venture like the International Center for Distance Learning, Inc. in Boston (www.ICDLcourses.com) that offers degree and certificate programs, as well as business training and others; to big venture capital enterprises, like UNext.com. UNext.com, reaching over 100,000 learners now, is hoping to grow quickly to over 1 million learners. It is partner with top-ranked universities such as Stanford University, Columbia University, University of Chicago, Carnegie Mellon and the London School of Economics to create an elite online academic institution, Cardean University, specifically designed to serve the needs of Fortune 500 companies, as well as individuals abroad. The company's investment in the creation of each course is very substantial, in the order of over $1 million per course. This is clearly something that cannot be matched by academic institutions. Yet, numerous "born on the web" universities are also tapping into the corporate market. For

example, some of the prominent ones include:

> The National Technologic University consists of 50 of the top engineering schools in the US including the Massachusetts Institute of Technology and University of California, Berkeley. It is to provide the best of the best courses through both the Internet and/or satellite; and
>
> The Calibre Learning Network consisting The Wharton School, Georgetown University, University of Southern California Marshall School of Business, Teachers College of Columbia University, and Johns Hopkins University School of Medicine, is to provide best quality distance courses for their corporate clients.

So, these alliances have moved the academic content beyond the institutions' classrooms into the business world.

On the global scene, similar explosive activities can be felt. For sometime we are aware of the partnership between MIT and the two major universities in Singapore – National University of Singapore and Nangyang Technological University.

In February 2000, the British government announced a distance-learning project for higher education that officials said was designed to give U.K. higher education the capacity to compete globally with the major virtual and corporate universities in the United States and elsewhere, as reported in the March 3, 2000 issue of *The Chronicle of Higher Education*, p. A41. "The venture, whose working title is e-University, will be jointly established, owned, and operated by a consortium of higher-education institutions working with the private sector and overseas partners...A prime impetus behind the eUniversity project is an effort to expand Britain's share of the overseas higher-education market, as well as to fulfill the government's goal of providing lifelong learning by increasing professional-development and vocational courses."

In that same issue of *The Chronicle of Higher Education*, it was reported "The World Bank's Global Distance Learning Network is scheduled to begin operating this summer, with courses initially delivered to 10 nations. The network will use the Internet, videoconferencing, and satellite links to connect "learning centers" at participating institutions." Under an agreement, the National University for Distance Education (UNED), in Madrid, will provide courses for delivery in Latin American countries, including Bolivia and the Dominican Republic. The UNED (http://www.uned.es) is among the first in developed countries to agree to provide content for the project. "This is a landmark step forward in enabling developed and developing countries to become partners in sharing and using knowledge and learning as an effective development tool," said the bank's president, James D. Wolfensohn.

Content Development and Online Courses

While online courses and campuses are springing up everywhere – both offered by traditional higher education institutions and commercially, one key concern and highly debatable question got to be related to the "**quality**" of these courses. There will continue to be the most challenging considerations for all of us for a long time to come. In addition, there are instructional design and development issues for web courses and web-enabled courses. These include:

- Types and levels of web courses,
- Strategies for student interaction and learning
- Selecting web templates, and
- Course management

Tools

Currently, many tools are available for course development, online course delivery, and teaching and learning with Web and distance learning technologies. Let me just name a few in the following:

Blackboard [www.blackboard.com] – Claimed to have been used by over 1000 institutions in every state of the US and in more than 60 countries.

eCompanion [www.eCollege.com] – Designed for faculty who teach in a classroom, but want to put the power of the Internet to full use. It has all the features of eToolKit, plus it allows you to make lectures available, conduct online practice tests, guide students to Internet resources, share documents and continue

class discussion outside the classroom.

eCourse 4.0 [www.eCollege.com] – an easy to use set of tools for managing and delivering online courses over the Internet. It includes course management, outlining assignments, delivering lectures, testing, grading and interacting with students.

e-education [www.jonesknowledge.com] -- online software from JonesKnowledge.com for both administration and faculty.

WebCT [www.webct.com] – Used by a number of universities in development their web-based courses. For example, Marshall University, an institution of 16,000 students, has 400+ courses and 6000+ students enrolled in classes that use WebCT for delivery of instructional material.

Education professionals can gain valuable knowledge about using Web-based or Web-supported teaching and for supporting distributed learning and/or distance learning programs since there are sufficient reporting in both literature and conferences. We are having some reporting at this meeting as well on this topic.

3 IMPLICATIONS FOR EDUCATORS

It is clear that in this millennium, as the personal computers and laptops become more and more affordable, and access to the Internet becomes common place, the computer-based learning delivery systems will predominate on the new distance learning frontier. As stated by Andy DiPaolo, Director of the Stanford Center for Professional Development, there is "a seismic shift from the campus-concentric to student-concentric" learning in a culture that has been moved from place-based to information-based. He also stated "In the industrial age, we went to school. In the communication age, the school comes to us" (Computer-based learning, January 7, 2000).

In this environment, the educators need to realize that there are many parties fighting for the "learning" turf. With many high-capital commercial .coms as key players, this has not been an easy time for many traditional educational institutions, particularly when the enrollment of some of these institutions are shrinking. News media reports frequently teachers' and educators' attempts to block the accreditation of online colleges, particularly those proposed by a commercial venture, such as the recent case with Harcourt Higher Education and the accreditation of its online college by the Massachusetts Board of Higher Education (Soule, September 3, 2000). Main reasons for objection tend to center around the doubt on these the online colleges' ability to provide quality education and to meet the same educational standards. Yet, supporters for virtual universities argue that they can indeed meet high standards. In fact, in a recent survey from Michigan State University on the educational success rate of exam performance of 200 undergraduates taking a macroeconomics introductory class, students taking online courses were found to score higher on exams than their classroom-bound counterparts.

Thus, attempting to block the online learning offerings at this time will likely be a futile exercise. Like it or not, we need to realize that distance learning technologies – primarily the Internet – have changed the way education will be consumed in the future. Like a tidal wave, online learning offerings will be introduced in different formats from different public and private, educational and commercial entities in great speed and quantity, and are not stoppable.

Instead, we educators should make more effort to explore computational media, to determine what technological base can best serve education and to find the most flexible systems to create web-based courses so to empower our teachers and students (Disessa, 2000).

4 IMPLICATIONS FOR INFORMATION PROFESSIONALS

Finally, I would like to close my talk on the implications of eLearning for information professionals. On September 20, 2000, on my trip back from Washington DC, I notice an interesting statistical chart on digital book sales on the first page of the *USA Today* of that day, as show in Figure 3.

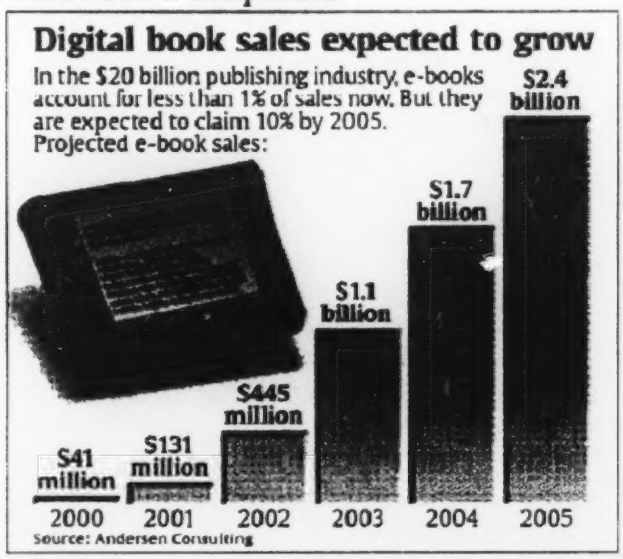

Figure 3. Digital Book Sales over from 2000 to 2005 (from USA Today, September 20, 2000, p.1.)

As online distance learning offers the possibility of overcoming both pedagogical and physical limits of traditional education, we need to realize that quality online education needs to be supported with needed information resources which must be "digital." Although many people consider the Web as a huge "digital library," yet, the quality of information retrievable from the Web is often questionable. I believe that everyone will agree that no quality education – online or traditionally class-bound – can be achieved without the support of information resources available from information rich places like libraries. Yet, most libraries in academic and other institutions are current not digital. While digital libraries are beginning to be created, most of our students and faculty in academic institutions are still obtaining their needed information resources from the hard-copy books, journals, and reports. While some small-scale digital libraries are available, they are mostly limited distributed systems that often cannot be interoperable, and have limited interactive and retrieval capabilities. We face many challenges in this area.

Figure 3 shows that currently in the $20 billion publishing industry, e-books account for lesst than 1% of the sales now. But they are expected to claim 10% by 2005. This is certainly a positive and needed development, in line with the demand resulted from the growth of eLearning.

Nevertheless, we need to remember that a great majority of our hard-copy information resources currently available from our academic libraries are not available digitally. Efforts need to be made to find ways to link the eLearning to the use of these resources.

In the last decade, I have advocated the need to develop global digital libraries so that, quality information resources cannot only be shared globally, and can also be available to us at our fingertips. Currently, my own effort in leading a major International Digital Library Project, called Chinese Memory Net, supported by the US National Science Foundation, is a collaborative

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R&D project working with researchers in interdisciplinary fields in China, Taiwan and the USA on various problems and issues related to the global digital library development. A major international conference, *NIT 2001*, will be held in Beijing. As shown in the graphics, it is organized by me to address some of the essential problems and issues related to global digital libraries. More information on this can be found at http://web.simmons.edu/~chen/nit.

5 CONCLUSION

Chancellor Robert Berdahl of the University of California, Berkeley has stated, "distance-learning promises to transform the manner in which education -- or, perhaps more accurately, teaching materials – are delivered around the world."

As the world economy is shifting its emphases from manufacturing to service jobs, and human capital is replacing physical capital as primary productive asset to human capital (Moe & Blodget), we can understand why education has emerged to become the second of the four top sectors in the US domestic economy – Health, 14.1% of GDP; Education, 9.5%; Social Security, 5.0%; and Defense, 4.0%. The significance of the education sector is likely to be found in many other developed countries in the world.

eLearning has transformed to be a killer application in this new millennium, and we must prepare ourselves to capitalize this technology environment, and to capture the opportunity to advance both the quality of our educational content delivery and to provide wider access for our citizens and students to better educational opportunities. It is an understatement to say that we are living in a very interesting time. Let's prepare ourselves well to be a proactive mover of this tidal wave.

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Social and Technological Innovations for a Knowledge Society

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Knowledge building--the creation of knowledge as a social product--is something that scientists, scholars and employees of highly innovative companies do for a living. We have demonstrated that these same activities can be integral to schooling, grades one to post graduate, and extensible to a variety of health care and workplace settings. The central purpose of CSILE (Computer Supported Intentional Learning Environments), and now second-generation Knowledge Forum®--and the Knowledge Society Network that it enables-- is to democratize knowledge. The most radical possibilities arise from restructuring the flow of information within and between organizations so as to allow participants to work continuously at the edges of their competence and to marshal high levels of "collective cognitive responsibility" and "collective intelligence." The ubiquity of such human capabilities, rather than ubiquitous computing, information access, and content delivery, will define a knowledge society.

Keywords: **innovation dynamic, knowledge creation, knowledge society**

1 Introduction

Twenty-first century knowledge work and technological innovation are inextricably related, as suggested by the global economy, the ever increasing demands for knowledge management resulting from the digitization of the world's knowledge resources, and the increasingly familiar *e-* prefix to signal electronic conversion of myriad forms of communication and commerce. Information-age societies will be founded on new knowledge media and on the redefinition of social and cultural practices afforded by them. While there is general agreement that the much heralded 'knowledge society' will have profound effects on our health, educational, cultural, and financial institutions, there is little analysis of the inner workings of such a society: Do we actually know how to promote the skills and the processes that would make a knowledge society work? Is it even legitimate to speak of a knowledge society if the majority of citizens do not belong to it?

The transformation from an industrial society with a manufacturing economy, to that of a knowledge society with a knowledge economy, represents a transformation comparable in significance to major transformations from prehistoric and historic times. Since the beginning of civilization technology and social innovations have been intertwined. These transformations are occurring at an ever quickening pace, and each involves technology breakthroughs and new social forms that are in reciprocal relation to one another. A very rough chronology, as presented by Keating & Mustard (1993) [1], is presented in Table 1.

Date	Technology Innovation	Social Innovation	Overall Result
40,000 B.C.	advanced stone technology	intertribal communication	recognizable civilizations with characteristic crafts and symbolic art
10,000 B.C.	the agricultural revolution	massing of populations in fertile regions	state structures and cumulative knowledge growth

1700 A.D.	machine technology	complex organizations of labor and capital	global trade and communication; specialization of knowledge production
2000 A.D.	advanced information technology	knowledge-based societies and economies	???

Table 1: Major transformations attributable to an innovation dynamic involving technological and social innovations

There is nothing new in the dynamic that binds technological and social innovation together. What is new is the purposefulness with which this dynamic is harnessed to specific achievements. In earlier times, major transformations occurred without plan. The industrialization of Europe and North America during the 19th century came about through the cumulative effect of countless individual initiatives with no overall plan. But in the 20th century we saw many nations embarking on plans for deliberate industrialization. Now we see nations the world over, developing policies to ensure a place for themselves in the global knowledge economy. The result of the 2000 A.D transformation is, of course, yet to be determined, and it may be different in different societies. According to one scenario, technological advances will democratize knowledge. According to another scenario, there will be a widening split between educationally advantaged and disadvantaged groups, leading to the rapid decline of nations and groups that are unable to keep up with the increasing demand for knowledge and skills.

2 Capturing the knowledge-creation dynamic

An innovation dynamic favorable to the creation of a knowledge society is enabled by social and technological systems working in reciprocal relation, each biasing knowledge work toward increasingly high-level processes. Democratization of knowledge additionally requires systems that *enable rather than presume advanced knowledge processes*. We refer to the social and technological systems that enable advanced knowledge processes as knowledge building systems because they engage all community members in the core knowledge creation dynamic: ideas and achievements are continually contributed to the community, and their usefulness is magnified through availability and continual refinement in a community context.

The last row of Table 1 is reproduced as Table 2, reframed to indicate knowledge building innovations hypothesized to lead to the democratization of knowledge--an optimistic version of the 2000 A.D. transformation.

Date	**Technology Innovation**	**Social Innovation**	**Overall Result**
2000 A.D.	Knowledge Building Technology	Collaborative knowledge-building communities, embedded in a Knowledge Society Network	The democratization of knowledge

Table 2: The knowledge building innovation dynamic

2.1 Core facets of knowledge creation

The knowledge-building innovation dynamic is elaborated in Table 3. It begins with a brief account of four facets of knowledge creation, which take into account frequently cited characteristics of twenty-first century knowledge work, including teamwork and knowledge sharing [2] [3] [4].

In this paper terms are used that signify the ways in which these aspects of knowledge work must be extended beyond their common meaning if the result is to be knowledge creation. Thus, for example, we use the term community knowledge. Teamwork is involved, but the production of community knowledge additionally requires that all members add value to shared ideas; otherwise, teamwork settles into joint productions that do not extend the team's knowledge. Team members enjoy information access, but access does not lead to knowledge creation. The four facets of knowledge creation presented in Table 3 are:

2.1.1 Community Knowledge

Expert knowledge-based societies are believed to gain advantage through collective contributions--what we might think of as knowledge-in-the-aggregate as opposed to the talents or contributions to knowledge of individual outliers. A growing literature suggests that the pursuit of excellence in a knowledge society will depend increasingly on what have been termed "21st Century skills" and the teamwork they imply. "In the knowledge society it is not the individual who performs. The individual is a cost center rather than a performance center. It is the organization that performs." [5]. There will be a premium on abilities over and above those that marked genius in previous centuries. Emphasis on individual excellence may even prove counter-productive to societal excellence.

2.1.2 Rise Above

It is easier to deal with the concrete, immediate, and simple than to cope with complexity, diversity, and messiness. Yet these later qualities typify most innovative environments and work at the cutting edge of a discipline. In knowledge building communities rise-above is built into the social fabric of the organization and into the technologies that support it. Its members establish shared goals that stretch their collective abilities. They move to increasingly high levels for resolving conflicts and for solving problems, thus they learn to accommodate emergent goals rather than working with goals that are fixed from the beginning. They learn to do the exceptional routinely.

2.1.3 Improvable Ideas

The history of scientific achievements teaches a lesson: ideas are improvable. Aristotle's physics was superseded by Newton's; Newtonian physics gave way to Einstein's relativity theory; relativity was further advanced by Planck's quantum theory. We still think of Aristotle, Newton, and Einstein as geniuses, but people who hold physical beliefs similar to Aristotle's are considered to hold misconceptions while contemporary physicists pursue theories that continue to advance improved versions of last year's theories. Creating knowledge new to the world, improving on existing knowledge, and grasping and applying what others say are all similarly intensive knowledge processes. Those who are able to continually build more complete knowledge are engaged in the same processes through which expert knowledge is achieved in the first place.

2.1.4 Symmetric knowledge advancement

This is a variant of what is popularly known as creating win-win situations, applied to knowledge work. Knowledge building is served when one group's knowledge serves as foundation for work elsewhere. Many institutions represent the antithesis of a model of 'symmetric knowledge advance.' Activities typically are organized so that participants do the same thing and do not learn from one another. For example, in educational contexts the teacher's knowledge does not advance appreciably in the course of instruction; outputs have no value outside the organization, except in rare cases where reports have value to others; and organizations--especially schools--form a distinct and separate community, minimally affected by knowledge advances in other sectors of society. The situations we wish to explore, in contrast, maximize knowledge resources through creating more synergistic relations both within and between communities engaged in knowledge work.

Nonaka and Takeuchi [6] present five phases of a knowledge-creation process: (a) sharing tacit knowledge, (b) creating concepts, (c) justifying concepts, (d) building an archetype, (e) and cross-leveling knowledge. The goal in listing facets of knowledge creation, as presented above, is not to identify steps in a linear process, nor an exhaustive classification, but rather to illustrate the correspondences between essential processes and technological and social supports that enable them. A row-by-row review of Table 3 highlights these correspondences, and planfulness in aligning them with technological and social innovations fine-tuned to their production. The implication is not that there is a one-to-one correspondence between these processes and these innovations. Rather, there is productive redundancy, with many routes, and no set pathways to the complex of socio-cognitive processes supported by knowledge building technologies.

Core Facets of Knowledge Creation	Technology Innovation: Knowledge Forum® *Bolded items refer to processes specifically supported by Knowledge Forum software*	Socio-Cognitive Innovation: Collaborative Knowledge Building Knowledge Society Network
Community Knowledge Contribute to collective knowledge advancement and shared goals; contribute ideas to communal design spaces; serve as a valuable team member; cultivate openness in knowledge work	Individuals and teams **contribute** ideas in the form of **notes** and **views** to **collaborative** and **public design spaces**; ideas are shared and refined as collaborators **read, build-on, reference, search, summarize,** add **keywords, collect** and **annotate** knowledge artifacts contributed by participants. Openness in knowledge work is supported through **links** to views of different team members and to the production of higher-order **conceptual frameworks**	Knowledge jointly constructed; priority given to the production of ideas of value to others, not simply to demonstrations of personal achievement
Rise Above Move to increasingly higher levels to resolve conflicts and to solve problems; transcend expectations; accommodate complexity, diversity, and messiness; translate ideas into action and new contexts; engage in progressive problem solving and self assessment	**Rise-above notes** and **views-of-views** support increasingly high-level formulations of problems and ideas, as well as **coherence** and **synthesis** of ideas; the rise-above-it principle is reflected in **publication-and-review, in a multimedia journal,** in individual and group **portfolios** and in **multiple representations** of ideas, viewed from **different perspectives;** customizable **scaffolds** for high-level knowledge processes support **theory refinement**, evaluation of **evidence** and **counterarguments, constructive criticism, experimentation,** and a host of high-level knowledge processes.	Community members view conflicts and problems from high-levels; they engage in theory refinement and explanatory coherence: Do our ideas fit together? Where are the gaps in understanding? What new information has been found that we must take into account? What is missing from our current conceptualization?
Improvable Ideas Cultivate promising and improvable ideas; sustain inquiry at the edges of understanding; move beyond current best practices; work with emergent goals; approach problems as opportunities	Idea improvement is supported through **peer review, coauthored** notes and views, **links** to **views** of different team members, higher-order **conceptual frameworks, reorganization** and **revision**, and integration of **new information; process models** and **knowledge-building discourse** are supported through **animation** and **video notes** **Analytic tools** work in the background and record processes automatically--**research** and **reflection** become integral to the workings of the organization; participants serve as ethnograpers of knowledge building.	Communities living at the edge of their collective understanding, sustained by a culture that prizes reflection, critical analysis, emergent goal states, and high-level integrations that do justice to the ideas of all contributors

Symmetric knowledge advancement Progressive refinement of ideas within and between communities; work at the cutting edge of inquiry; situate and refine ideas in the context of broadly distributed communities	Interleaved **local-and wide-area networks** support the work of **local and globally configured communities**; **replication, merger** of workspaces, and a system of **virtual visitations,** support **knowledge building discourse** within and across communities; online-offline **synchronization**, wireless capabilities, and **Palm KF** will soon provide **anytime, anywhere access**	Distributed and opportunistic workgroups treat diversity as strength and enable integration of work across disciplines and communities

Table 3: The knowledge-building innovation dynamic: core facets of knowledge creation, knowledge building technology, and knowledge building social structures

2.2 Knowledge building technology

Column two of Table 3 indicates technology supports to enable the core facets of knowledge creation listed in Column 1. The technology that provides these supports is Knowledge Forum, a second-generation CSILE (Computer-Supported Intentional Learning Environment) product [7] Knowledge Forum is designed to make the underlying, hidden aspects of knowledge creation transparent to its users. There is not space to elaborate here, but we have found that the facets of knowledge creation listed above are in evidence with Grade One students using Knowledge Forum. This finding is suggestive of the goal underlying its design--to provide 'a way in' for everyone, and thus to take the essential first step in democratizing knowledge. These same processes are supported by the same technology and the same social structures in health care, graduate school, business, cultural organizations, and other workplace environments. Thus we have demonstrated that these activities are integral to schooling, grades one to post graduate, and extensible to a variety of health care and workplace settings. This opens the way for a knowledge society.

2.3 Knowledge building social structures

Column 3, Table 3 indicates the social innovations that correspond to Knowledge Forum's technological innovations and, in turn, to the core facets of knowledge creation it is designed to support.

2.3.1 Knowledge building communities.

Knowledge-building communities [8] are not simply collections of people who individually pursue knowledge, even though their individual interests may be diverse. They are a community in the sense that they share their knowledge, support one another in knowledge construction, and thus develop a kind of collective expertise that is distinguishable from that of the individual members. Participants may be co-located or distantly located. The defining characteristic is their commitment to the collective goal of improvable ideas--the essence of knowledge creation. Advancement of knowledge is pursued strategically and with deliberate investment of resources. Participants aim to redefine problems at deeper or more inclusive levels as they proceed rather than to eliminate problems. The result is continual advancement of the community's knowledge and capabilities, similar to the process of expertise in cutting-edge research and development teams [9] [10]. Although knowledge creation depends on chancy processes of discovery and invention, we take it for granted that some communities will make advances with greater regularity than others. That is what we expect of knowledge building communities, as they represent a social organization that invests its resources in the advancement of the group's knowledge, so that the group as a whole is striving for advancement beyond present limits of competence.

Participants within a knowledge building community, supported by Knowledge Forum, share an electronic design space in which important aspects of their intellectual work are recorded in digital form and entered into Knowledge Forum's communal workspaces. Processes of reflection, review, and publication encourage each community to create high-level syntheses of their work. Analytic tools work in the background of these design spaces and record processes automatically so that research becomes integral to the day-to-day workings of the organization, encouraging the community to reflect on their processes and to continually improve them. The design spaces support multimedia--video, animation, audio, graphing--and cross-application inter-operability is on the design agenda. Knowledge building discourse is the dynamic that brings various knowledge operations into the service of knowledge advancement.

2.3.2 The Knowledge Society Network.

Experts seldom exist in isolation. Nor do expert communities. Often they are linked together by associations or informal networks, but even when that is not the case they are connected through a tradition in which expertise evolves over generations. Globally networked knowledge building communities enable the Knowledge Society [11]-- a network of networks, providing a natural extensions of the progressive refinement of problems, knowledge sharing, and group interactions that define work within a community. Knowledge Forum supports this process through integration of knowledge work within and across communities. Select portions of the design spaces of local communities can be opened to cross-community searches. Features such as replication and merger of design spaces allow communities to replicate portions of one design space into another and to create new cross-community discourses. Thus, for example, elementary school biology communities might work with high school biology communities, and they in turn with pre-med students. However, there is no predetermined alignment, and communities may find their cutting edge in unanticipated places. The work of these communities is enriched by virtual visitations, and also made increasingly demanding by the commitment to openness in knowledge building that these visitations entail. Participants agree to allow their design space to serve as an object of inquiry, giving new meaning to work at the cutting edge. By making use of talents within and between communities, knowledge building communities have access to enhanced knowledge resources, and continual effort does not have to be exerted to make the system function, as knowledge building is built into the dynamics by which participants communicate and pursue organizational goals.

3 Conclusion

Knowledge creation must operate at all levels of an organization and across a wide range of organizations if we are to democratize knowledge. In order for this to happen, both technological and social innovations are required that go beyond what is presently regarded as the state of the art. Inquiry into the social and technological innovations required for a knowledge society is in its infancy. The goal of this paper is to contribute to an understanding of the issues and possibilities of a special form of a knowledge society--one that enables rather than presumes advanced knowledge processes; one that is committed to giving away its understanding of these processes.

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Computer-Based Strategies for Articulate Reflection (and Reflective Articulation)

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In 1993, the last time ICCE was in Taiwan, theories of situated cognition were promising to change the field of educational computing. What has happened since? It seems that many of the superficial interpretations of situated cognition (that thinking is a physical skill, that knowledge cannot be separated from activity, that learning takes place through participation and not in an individual mind) have been sufficiently refined that they may be considered to accord with current emphases on collaborative learning environments. However, the precept that "'situated' means coordination without deliberation", which, superficially (and, of course, situationists would attempt to clarify that it is much deeper than this), seems to reduce cognition to unreflective practice does not appear to correspond to current system designs. There is now an increased emphasis on learning systems providing an environment not just for practice but also for articulation and reflection. The reasons for this will be discussed and some strategies for promoting articulate reflection will be illustrated with reference to five systems: EUCLID (for geometry problem-solving), BSL (for understanding floating and sinking), STURM (for supporting essay planning), MArCo (for group planning) and STyLE (for learning terminology).

Keywords: system design, reflection, articulation

1 Introduction

The aim of this paper is to consider trends in the development of advanced computer-based learning (CBL) systems in the last decade and, in particular, to focus on strategies for supporting articulate reflection by students. In 1993, the last time this conference was held in Taiwan, there was a heated debate underway concerning the implications of situationism or situated cognition, a specific form of constructivism, for the design of CBL systems. Proponents of this philosophy of cognition considered that a revolution in the way we conceptualise CBL system design was needed.

We do not hear so much about this debate nowadays (for example, at the recent AIED and ITS conferences there was barely a mention of situated cognition). What has happened? Has the theory been abandoned? Has it been entirely accepted, so that there is nothing left to debate? Have some of the tenets been quietly absorbed and some put aside?

The tenets of situationism always seemed rather elusive in the sense that the simplistic slogans which were sometimes put forward to summarise the revolutionary nature of the theory were inevitably accompanied by detailed discussions indicating that the slogans never quite captured the essence of the theory. What appears to have happened over the last decade is that the tenets have been refined so that they no longer seem so revolutionary - and indeed current system designers unaware of the previous heated debate might well wonder what all the fuss was about. For the simple fact is that researchers and designers are situated too. What they do is determined also by their community of practice and environment, and, obviously, over the last decade there have been major changes towards networked learning and lifelong learning, with which situationism is more in tune than the traditional symbol-processing forms of cognitive science, more appropriate for individualised, adaptive systems.

However, there is one current trend in CBL systems, the focus on supporting articulate reflection, which it is difficult to relate to the principles of situationism. Of course, situationists had much to say about articulation and reflection (along with everything else) but most of it appeared to be rather confused. As we will see, this is basically because situationism is a theory of knowledge and performance and not directly one of learning.

In this paper, we will briefly discuss the nature of situationism and consider trends in the design of CBL systems. After considering articulation and reflection in more detail, we will then present various strategies for supporting articulate reflection, illustrated by specific CBL systems, leading to conclusions about CBL system design.

2 The tenets of situationism

Situationism is one of many variants of constructivism. The defining characteristic of constructivism - the principle that learners construct knowledge and do not somehow passively receive or absorb it - is hardly arguable. The corollaries which are emphasised begin to be more questionable:

- that an essential part of what is learned is the context in which learning takes place (both the physical and social environment);
- that knowledge is constructed by learners through actively interacting in situations in which they experience a domain;
- that previously constructed knowledge influences the way learners interpret new experiences and affects their thinking and learning;
- that construction of knowledge occurs over time from the learners' attempts to connect new and previously developed experiences.

Situationism departs from other forms of constructivism in its view of what it is that is constructed. Non-situationists need not necessarily deny that knowledge construction leads to symbolic representations or cognitive structures held in the brain (as conventional cognitive science might be considered to hold). Situationists do not agree that the 'construct' is an entity in this sense.

The following appear to be the main tenets of situationism (although it is risky to present such a brief list because situationists will always say that matters are really much more complicated than this):

- Knowledge is an analytic abstraction, like energy, and not a substance or thing that can be inventoried [3]. It does not reside "in the heads of tutors, getting there through experience, abstracted but not necessarily accessible in an articulatable form", as asserted in [16]. Knowledge may be represented symbolically, for theoretical purposes, but such symbolic representations are not themselves knowledge, no more than a map is the territory mapped.
- The activities of a person and an environment are parts of a mutually-constructed whole. A person does not act *in* or *on* an environment (or vice versa) but *with* an environment. Therefore, one cannot describe either separately but only in terms of their contributions to an activity. The mind is then a functional property of this interaction between a person and an environment, not an entity that exists in the head. Perception and acting are mutually shaping, or "'situated' means coordination without deliberation" [1], a phrase subsequently elaborated to mean much more than it appears to say.
- Language is the "instrument of social cooperation and mutual participation" [7], rather than a means of describing some separately given reality. Therefore, language is the means to enable learners to participate in a jointly constructed social activity rather than to transfer reality from one head to another.
- Learning is "a process that takes place in a participation framework, not in an individual mind .. learning is, at it were, distributed among co-participants, not a one-person act [11]. This proposition seems less counterintuitive once it is clarified that 'social' does not mean 'in the presence of other people': "an action is situated because it is constrained by a person's understanding of his or her 'place' in a social process" [3]. So an individual reading a book may be situated and engaged in a social process.
- In general, situationism begins with practice and works towards theory (rather than vice versa, as attributed to the symbol-processing paradigm). There is, therefore, an emphasis on learning from apprenticeship, rather than from teaching or formal schooling. This denial of the role of theoretical abstractions, necessarily situation-independent, does, of course, create difficulties with the notion of 'transfer'. One could deny that transfer ever happens [5] or attempt to provide a situationist account of the apparently contradictory notion of transfer ([10], a lengthy but ultimately unconvincing article).

It was striking that the studies that led to the theory of situated cognition were mainly studies of performance (grocery shopping, Liberian tailoring, reasoning about land rights in the Tiobriand Islands) and not of learning (e.g. of how a Liberian tailor becomes competent). It was rather assumed that the only or the best way to acquire the situated knowledge that people appear to have was for them to be immersed in the 'community of practice' - as if, after observing expert skiers on the mountainside one concluded that a novice skier should learn within that community, when in fact the opposite happens, with novice skiers being excluded until they are capable of joining. It was also implicit that because knowledge was observed to be situated this was therefore a desirable state of affairs - that it should be the aim of education to help learners acquire such situated knowledge.

In response to the question "So, what should we as system designers do differently, according to situation cognition?" a list [2] was provided (where I have omitted the "rather than .." clause which ended each item, in order to focus on the nature of the proposal, not its purported contrast with alternatives):

- participate with users in multidisciplinary design teams
- adopt a global view of the context in which a computer system will be used
- be committed to provide cost-effective solutions to real problems
- facilitate conversations between people
- realise that transparency and ease of use is a relation between an artefact and a community of practice
- relate schema models and computer systems to the everyday practice by which they are given meaning and modified
- view the group as a psychological unit.

As we look at the list today we may conclude that it is not so controversial. Situationism has been sound in its broad proposal - that we would do better to concentrate on restructuring the social-cognitive settings within which students learn than to try to manipulate the internal information-processing of students. However, there is one aspect which is missing, or at most muddled, within situationism and that is the role of activities specifically to aid learning (not performance), such as articulate reflection.

3 Reflection and articulation

By *reflection* we mean more than 'deep thinking', as in the everyday sense. We mean the consideration of one's own thought processes, problem-solving strategies, knowledge and skills. In short, thinking about one's own thinking. In general terms, this reflection needs to be both motivated (so that the learner feels there is some potential gain in pausing during the problem-solving process) and supported by some kind of externalisation of the learner's thought processes (so that there is something upon which the reflection may focus).

Reflection is therefore an interruption to action. With competent problem solvers, where there is no intention to seek improvement in any related activity, there may well be no reflection. If situated cognition implies action "without deliberation" then this appears to leave no place for reflection, although it has always been a key component of cognitive apprenticeship [4]. Reflection was considered to be the fourth and last stage of the cognitive apprenticeship process. However, it was considered appropriate only in domains for which the target process is external and thus readily available for observation and comment and also bears a relatively transparent relationship to concrete products.

Articulation is the process of verbalising, for the benefit of oneself or others, the thought processes and problem-solving activities that are occurring or have occurred. Articulation is important for three reasons. First, at the philosophical level, the link between language and thought, the later sometimes being considered to be a kind of 'internal language', may mean that the act of making verbally explicit may in itself help develop the thought processes being described. Secondly, articulation may bring into the open current (mis)understandings so that they may be inspected, discussed and edited by oneself or others. Thirdly, being able to provide an articulate explanation is itself a worthwhile educational objective. Situationist researchers may be in awe of remarkable, but inarticulate, problem-solving processes but generally we prefer a solution which is accompanied by some explanation of how it has been derived.

For computer-based learning systems, we need to support *both* reflection and articulation together, neither alone being of much help to the system or the learner. The system needs to provoke reflection but it needs to receive some information about that reflection if it is to provide support.

4 Strategies for promoting articulate reflection

In this section, five strategies intended to promote articulate reflection are described, illustrated by projects underway at Leeds.

4.1 Present novel problems which require articulation for their solution

If one presents a traditional geometry problem (such as Figure 1, on the left) to an expert, a solution is obtained almost instantaneously, with the expert often being unable afterwards to say precisely how the solution was obtained. Asking the problem-solver to describe the process during problem-solving only interferes with the process. Such problems, characteristically, have the fortunate properties of being complete and non-redundant,

that is, every thing that needs to be known is in the figure and there is nothing in the figure which is not needed in the solution. Problem solvers therefore soon realise that any step is likely to be a useful one.

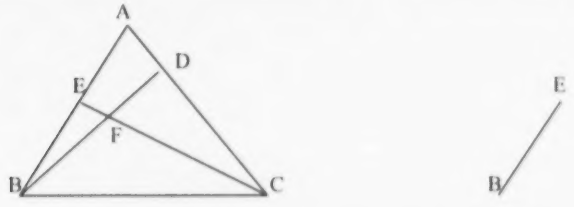
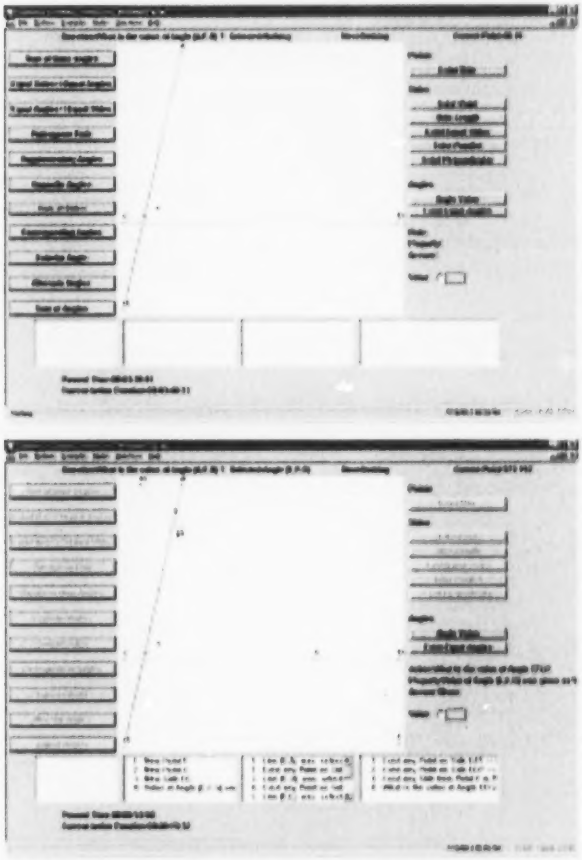


Figure 1. (a) A 'traditional' problem: Given BCF=FCD, CBF=EAD, BF=5, what is the length BE?
(b) An 'incomplete' problem: What is the length BE?



If, however, we present an 'incomplete' problem (Figure 1, on the right), then solvers have to think carefully before asking for information which they hope will be useful. For example, for this problem, we might ask:

"Is there a line parallel to BE?"

"Is there another line through point B?"

Even experts (at traditional problems) have difficulty in devising an effective series of questions for such problems. Generally, however, those with a better understanding of geometry realise that more 'conceptual' questions (such as those to do with parallel and perpendicular lines) are more useful than specific questions, because they are related to the inferences (opposite angles, exterior angle, etc.) which need to be made.

The EUCLID system (Figure 2) has been implemented to enable solvers to solve such problems and enable them to develop an understanding of geometry concepts. Users use the right menu to ask questions of various forms and the left menu to apply inference rules, thereby making explicit their problem solving process. The system records the questions asked and this provides a focus for reflection.

Figure 2. The EUCLID system, showing the starting problem (above) and midway through a solution (below).

The questions may be considered to be of four kinds: existence, value, conceptual, rule application. Users' strategies may then be plotted, showing differences between novice (focussing on specific questions) and expert (asking more conceptual questions) problem solvers [12].

Figure 3. A trace of two subjects' solution of the problem shown in Figure 2.

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4.2 Provide an appropriate language, especially where the proper language is too formal

Most people can venture an answer to a problem such as that shown in Figure 4, but find it hard to give a justification for their solution. They simply do not have the technical or everyday words to express their justification. Here are two typical explanations:

"The shape of the bottom of the boat is slanting and the gradual change of the slope… helps it float. In the block….no gradual change of slope….so it sinks."

"Something to do with the shape. Don't know why….saw on TV where the speed of motion depends on shape."

It does not help to provide a list of technical definitions (buoyant force, etc.).

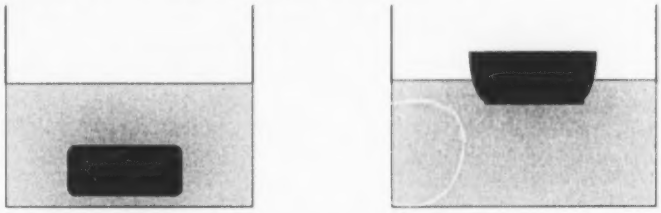
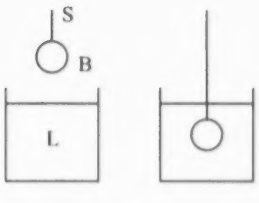


Figure 4. A floating problem: *A lump of plasticine sinks when it is placed in water. When the same lump of plasticine is shaped into a boat, it floats as shown on the right. Explain this phenomenon.*

Instead, we might try to provide an intuitive, informal language which may provide a bridge to the technical language. For example, consider the situation (Figure 5) in which a body B hangs from a string S above or in a liquid L (in a infinite container). B, S and L are the only things we need to talk about. What can we say if we make B heavier (but the same volume)? S has to hold it up a bit more. What if L is denser? What if B is a cylinder not a sphere? ... fairly soon, one starts using B, S and L for the forces associated with them (without, of course, necessarily using the word 'force'). Once one has this 'language', more complicated questions can be tackled: When a body is lowered into a liquid do B, S and L change in the same way if B is a sphere and a cylinder? How do B, S and L change if the body floats when it is lowered?



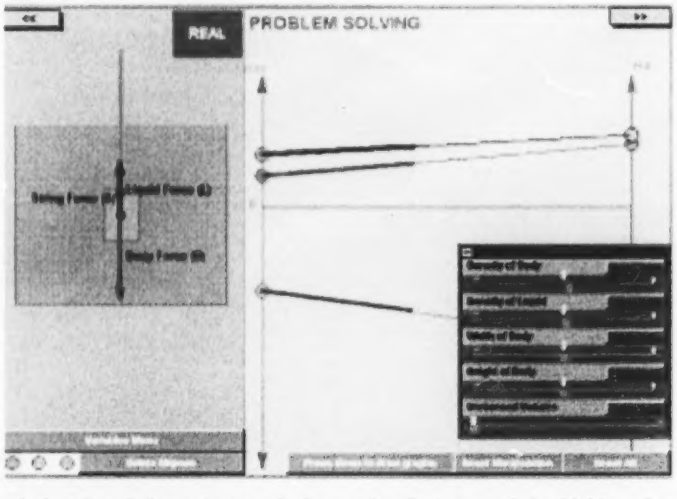


Figure 5. The BSL situation and the BSL environment for experimentation and problem solving.

The BSL system (Figure 5) was designed to help students articulate and reflect upon their thinking about buoyancy and floating concepts. The evidence is that students are enabled to provide more articulate explanations, and, through experimenting with the simulation, can test out hypotheses and develop conceptual understanding [13]. For example, here is an extract of an explanation given while using BSL:

S: "Increase depth of submergence….as you increase….body force will remain constant, I guess….your liquid force, I guess is going to increase because….due to the height….you are going deeper…"

E: "What height is that?"

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S: "The deeper....as you go deeper into the water, there is water pressure pushing it up. But I am not very sure about the string force...as you go deeper, the string force is getting less because of the upward force of the liquid....so....the thing is getting less....I think it's getting constant....I guess."

4.3 Monitor the student's activities and help him to articulate his problem-solving strategies

Imagine that you are a music undergraduate and you have been given the following essay assignment: "In what ways was Schumann a more romantic composer than Beethoven?" Imagine also that your tutor has kindly provided a list of potentially useful web addresses (music dictionaries, biographies, examples, etc.). How would you proceed?

The planning stage of writing involves goal setting, content generation and argument building. The potential argument structure of an essay should not emerge after all information has been gathered but should guide the information-gathering process. Therefore providing advice on appropriate research strategies should help students begin to build an argument structure from the material which they are reading. We have identified a number of strategies potentially useful for tackling essays of the form "Compare A and B with respect to X", such as:

- identify the characteristics of X (so that you may compare A and B with respect to each characteristic)
- see if the characteristics of X change over time (so that you may see when A and B best fit X)
- search for discussions of whether A (or B) has a specific characteristic of X or not
- consider whether there is an exclusive-or relationship between X and some Y (so that, if so, you might consider A (or B) with respect to Y

The STURM (Studying, Teaching and Understanding Research Methodologies) system has a catalogue of such general purpose information-gathering strategies. The idea is that as a student browses the web resources the system maintains a simple model of the information of which they are aware and then when a student asks "What should I do next?" it is able to provide advice, by determining which of its strategies are applicable at that time. For example, if the student has accessed a resource which suggests that a characteristic of romanticism is that it is more descriptive or programmatic than abstract a number of steps might be proposed, including an instantiated form of the third one above: "See if Schumann's music is descriptive". Of course, it is conceivably useful to present an abstract form of the advice, as being potentially helpful for all essays of this type. As the student carries out this browsing, what he discovers begins to form the structure of the essay. For example, finding out (from the second piece of advice above) that the notion of romanticism changed considerably from the Beethoven to Schumann eras provides one basis for organising the essay.

4.4 Require students to develop problem-solving strategies in a group and help to resolve conflicts

There has been much discussion of the idea that cognitive conflict triggers reflection. However, it is clear that such conflict does not always trigger reflection and, if it does, it is often quite shallow. Partly, this is because the notion of conflict is itself quite shallow, amounting to the holding of a proposition and its negation. The resolution therefore involves only the consideration of which proposition(s) need to be discarded. 'Strategy conflicts', however, are more subtle. If a strategy is a partially ordered sequence of steps to achieve some goal, then two strategies may conflict in various ways, for example, some of the steps may be out of order, different ones may be in parallel, etc. It is not always clear whether the differences are significant. If there is a significant conflict, its resolution involves more than just deleting one or more components. In short, the resolution of strategic conflicts is likely to provide a basis for deeper articulate reflection than ordinary cognitive conflict.

The MArCo system (Figure 6) is designed to support two or more students in group problem solving and then to resolve potential conflicts. Conflicts happen through dialogue and are inevitable in group problem solving, and, indeed, are beneficial to it. To provide support, the system needs first to model individual activities and to detect conflicts. We distinguish between a 'difference of views' (where agents have different views but have not yet communicated them to each other); a 'disagreement' (where the agents inform each other about their different views but a discussion does not then follow); and a 'conflict' (where the agents try to convince one another about their own points of view). Conflicts may be of various kinds [17]:

- non-task related or social conflicts
- belief conflicts, i.e. conflicts about facts and rules within the domain
- contextual conflicts, related to defining what exactly is the problem being solved
- reflector conflicts, related to how goals are selected

- intention conflicts, concerning the steps to be taken to solve a problem
- goal-definition conflicts, relating to defining the goal
- goal-achievement conflicts, concerned with disagreements about whether the goal has been achieved.

For example, a belief-conflict is defined as:

Bel_Conflict(x,y,s) = def[Bel(x,s) and Bel(x,Bel(y,~s)) and Intend(x, Bel(y,s))]

According to this definition, x has a conflict with y if x intends that y should change his belief to conform to x's, but not necessarily vice versa. We can also define a mutual belief conflict:

Mutual_Bel_Conflict(x,y,s) = def[Bel_Conflict(x,y,s) and Bel_Conflict(y,x,~s)]

The distinction is important because, in the first case, x may be mistaken about y's beliefs and the conflict situation may cause confusion, whereas the second situation has more potential for articulate reflection. Similarly, we define a collaboration and a mutual collaboration as:

Collab(x,y,p) = def[Bel(x,p) and Bel(x,Bel(y,p)) and Intend(x,strategy(x,p)) and
Expects(x,Intend(y,strategy(y,p)))]

Mutual_Collab(x,y,p) = def[Collab(x,y,p) and Collab(y,x,p)]

In a mutual collaboration, the strategy(x,p) and strategy(y,p) are interleaved or merged to contribute to a problem solution; in a mutual cooperation, the strategies are concatenated (i.e. they are independent and both contribute directly to the solution).

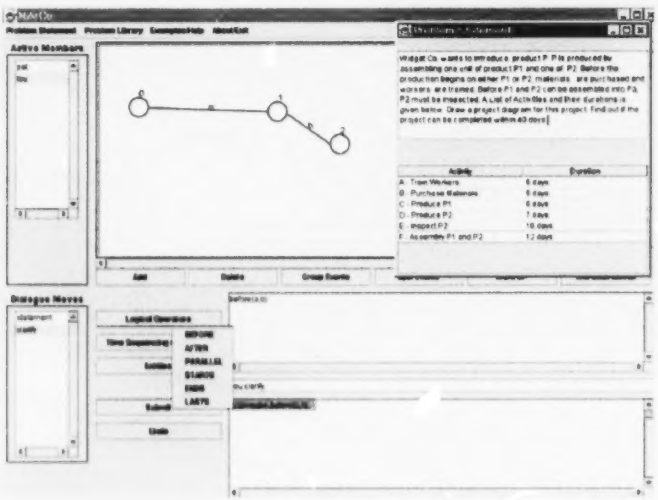

Figure 6. The MArCo system

The MArCo interface provides:

- a graph window, where members of the group build a common graphical solution
- a constraints window, where members may discuss the constraints and goals of the problem
- an active members window, showing who is involved in the discussion
- a dialogue region, where members contribute by selecting dialogue moves and selecting the content (from the graph window or the constraints window)
- a dialogue record, maintaining a history of the interaction.

On detecting a conflict, MArCo may (1) simply inform the group that a conflict has been detected, leaving the group to decide how to proceed; (2) after detecting a conflict, ask a member who has expressed a view different to the group model to elaborate on his apparent change of mind; (3) suggest actions that may lead to more refined solutions, by, for example, building up solutions involving more members of the group.

4.5 Present the student with a representation of his own understanding, which he may discuss and edit

Presenting the learner with an externalisation of their thoughts, e.g. System: "You seem to think that money markets operate with short-term investments", will not by itself provoke much articulate reflection. The system needs to be able to sustain a focussed interaction probing the justifications for such beliefs.

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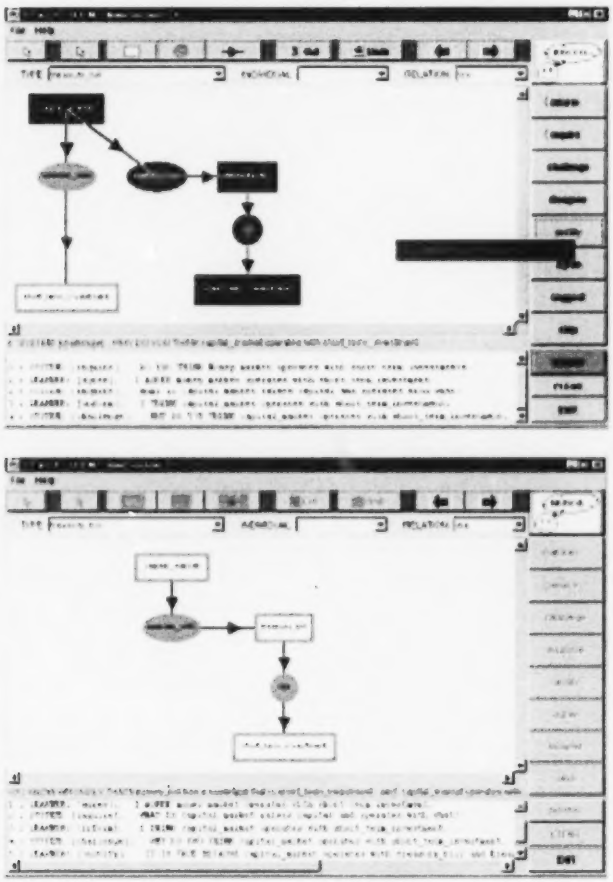
STyLE-OLM (Figure 7) is an environment for interactive diagnosis where a learner and a computer system are involved in an ongoing dialogue about the content of the learner model [8]. It supports the elaboration of the definitional structure of a terminology domain. It provides a communication medium based on a graphical representation of conceptual graphs that allows externalisation of the learner's conceptualisation of the domain and thus articulation of his domain structural model. An interactive model based on dialogue games maintains the communication between the learner and the computer.

Involving students in situations where they can inspect and discuss their models is a reflective activity which leads students to think about their domain knowledge as well as to articulate, validate, and challenge the robustness of their domain competence. STyLE-OLM provides a variety of reflective situations. It encourages the student to make statements about his beliefs and allows him to go back to his previous claims about these beliefs and (possibly) to change his claims. Throughout the interaction, the scope of the articulated beliefs is extending and he is provided a manner to explore various aspects and alternatives for expanding his beliefs. Additionally, the system leads the learner to search for and render grounds that support his beliefs.



STyLE-OLM provides two modes: DISCUSS, where a learner can discuss aspects of his domain knowledge and influence the content of the learner model (figure 7 above), and BROWSE, where a learner can inspect the current state of his learner model (below).

The graphical tools on the top allow the student to manipulate the graph that will present the proposition of his communicative act. He adds illocutionary force by selecting a dialogue move from the right area of the screen. Both the student and the system contribute to the discussion in the same way - by selecting a graph component and a dialogue move. The bottom text window shows a generated transcript of the dialogue. The learner can browse this textual form of the dialogue history or a graphical one. As the dialogue proceeds, the system makes plausible inferences about what further the learner believes on the basis of what is explicitly asserted, and from this a dialogue strategy is determined. The dialogue is guided by general explanations of misconceptions, for example, that an entity may be believed to be a member of a class if it has some features of that class. The example shown presents a situation of a session with STyLE-OLM in a Finance domain.

Figure 7. The STyLE-OLM system

STyLE-OLM is called by STyLE (a learning environment for Finance terminology) to solve problems with the diagnosis faced by the components that analyse a student's performance. In this example, initially, the learner model contains information that the learner knows some aspects of the terms MONEY_MARKET and CAPITAL_MARKET but often mixes these terms. STyLE-OLM initiates a dialogue to explore the learner's knowledge about these terms and to find possible reasons for his beliefs. This is an extract from this interaction (note that is a generated transcript - all communication is actually done graphically, using the graph and menus):

STyLE-OLM[inquire] DO YOU THINK MONEY_MARKET operates with SHORT_TERM_INVESTMENTS.
Learner[agree] I AGREE MONEY_MARKET operates with SHORT_TERM_INVESTMENTS.

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STyLE-OLM[inquire] WHAT IS CAPITAL_MARKET raises CAPITAL and operates with WHAT?
Learner[inform] I THINK CAPITAL_MARKET operates with SHORT_TERM_INVESTMENT.
STyLE-OLM[challenge] WHY DO YOU THINK CAPITAL_MARKET operates with SHORT_TERM_INVESTMENTS?
Learner[justify] IT IS TRUE BECAUSE CAPITAL_MARKET operates with TREASURY_BILL and TREASURY_BILL is a SHORT_TERM_INVESTMENT.

The screen shot in Figure 7 depicts the environment at the moment when the learner constructs and submits his justification. STyLE-OLM may continue the dialogue:

STyLE-OLM[challenge] WHY DO YOU THINK CAPITAL_MARKET operates with TREASURY_BILLS and TREASURY_BILL is a SHORT_TERM_INVESTMENT?

At this time the student may challenge the robustness of his domain beliefs. He switches to a browse mode where he looks through the current state of the learner model. The lower screen shot in figure 7 presents this stage. The learner realises that his claim that CAPITAL_MARKET operates with TREASURY_BILL and TREASURY_BILL is a SHORT_TERM_INVESTMENT is wrong. He can now ask the system to help him to explore the domain knowledge about these terms. The learner may switch back to a discuss mode where he asks questions:

Learner[inquire] IS IT TRUE TREASURY_BILL is a SHORT_TERM_INVESTMENT?
STyLE-OLM[inform] I KNOW TREASURY_BILL is a SHORT_TERM_INVESTMENT.

The learner now realises that this domain belief is correct and asks for the other part of his wrong belief:
Learner[inquire] IS IT TRUE CAPITAL_MARKET operates with TREASURY_BILLS?
STyLE-OLM[inform] I DO NOT KNOW CAPITAL_MARKET operates with TREASURY_BILLS.

The learner has now clarified the wrong part of his beliefs. Now, he could possibly withdraw his claim that CAPITAL_MARKET operates with SHORT_TERM_INVESTMENTS, ask what CAPITAL_MARKET does operate with, or explore his knowledge about SHORT_TERM_INVESTMENTS by making claims about other examples of short term investments.

5 Related work

There are, of course, other strategies for promoting articulate reflection not illustrated by the Leeds systems, for example:

- Use a 'reflective follow-up' in which, after a problem has been completed, the student is stepped through his solution steps in comparison with the steps that the system itself (as an expert problem solver) would have taken [14].
- Use a simulated peer (which has access to an expert domain model) to prompt a student to explain the reasoning behind his actions [9].
- Require students to complete self-explanations, that is, to provide explanations to cover gaps in worked examples [5].
- Provide an interface for students to express their theories of how to do inquiry [18].

Finally, to indicate that articulate reflection is not always beneficial, consider the following problem: "Two glasses, two inches and four inches wide, are both filled up to one inch from the top. Which glass has to be tilted the most before the liquid pours out?". When people close their eyes and imagine the glasses being tilted they always answer correctly - but when twelve pairs considered the problem and engaged in some discussion about it, none of them answered the problem correctly [15]. Evidently, there are times when articulate reflection in a group does not lead to productive outcomes!

6 Conclusions

Ideas about the design of computer-based learning environments have evolved over the last decade. We no longer have such heated debates about the implications of apparently contradictory philosophies. The tenets of what appeared to be the most revolutionary philosophy (situationism) have largely been absorbed, although there is, of course, much work to do to develop practical applied systems. However, this has probably occurred not as a result of any philosophical conversion but as a result of changes in the technological and social context, in particular, the growing emphasis on networked, lifelong learning. Somewhat paradoxically, however, situationism's genuflection to efficient and effective problem-solving performance, without apparent reflection or traditional teaching, led to a neglect of aspects which are crucial for learning, if not performance. In particular, the role of articulate reflection was never clearly integrated into the theory of situationism, because its ideas

about learning were inferred from its theory of performance. Computer-based learning systems designers, however, have proceeded to develop a number of strategies for supporting articulate reflection, as illustrated in this paper, indicating that they continue to be more influenced by their own communities of practice and social and technological contexts than by theoretical philosophies (as situationism would predict).

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